A SURVEY OF RATES OF WATER LOSS FROM LEAVES.*

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INTRODUCTION.

This paper is a record of data collected showing water loss from leaves from a number of plants growing in several habitats. As many different species as possible were tested in the time at the writer's disposal. At first a mere list of water loss data was intended, but a number of new phases have arisen during the course of the tests. It is probable that, as the work progresses and more is known about the general field, still others will arise.

Representatives of three of the four great groups of plants have been studied, namely from the Spermatophytes (including both Angiosperms and Gymnosperms), Pteridophytes and Bryophytes. The greatest number is from the Spermatophytes since they make up such a large proportion of our vegetation. The method used in collecting data was not applicable to the Thallophytes and submerged aquatics.

In collecting these data, representatives were selected from several different habitats so that comparisons of their water loss might be made. An attempt has also been made to study the diurnal rates of water loss from a small number of plants.

The water loss from plants has an extremely important bearing on their distribution and their survival. Heretofore, largely because of their economic importance, much more has been done with agricultural plants in this relation than with other types. And too, in nearly all cases potted plants, plants growing in the laboratory, in the greenhouse, or otherwise under abnormal conditions, have been used. This work is an attempt to measure the loss of moisture under as nearly normal conditions as is possible with present day methods. The loss has not been considered as a "power of the leaf", but rather as a phenomenon over which it has no control. Water loss is due to external and internal environmental factors rather than a specific "ability" of the leaf "to give off water."

As far as the writer has been able to discover, very little work has been done in the way of a general survey of water

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loss from leaves.* This is likely due to a lack of a practical quantitative method of determination, which can be carried into the field and used readily under natural conditions of the many different habitats.

METHOD USED.

The cobalt chloride paper test was used, as devised by Stahl (19), improved by Livingston (9), Livingston and Shreve (10), and more recently by Sayre (12). Livingston's and Shreve's method was quite an improvement over that of Stahl, and has been used successfully by a number of workers. However, it should be noted, that the results obtained by this method are entirely qualitative and relative.

To secure quantitative results Sayre (12) standardized cobalt chloride paper by the following method. Filter paper (Whatman No. 1) was saturated in a 3% solution of cobalt chloride, dried in an oven until the blue color appeared, and then continued in a desiccator containing anhydrous calcium chloride. Dry weight was then obtained, after which they were placed in a moist chamber and left until they attained a full pink color, and reweighed. The difference in weight represented the amount of water vapor necessary to change the blue paper to a full pink color.

From these data it is seen that if the cobalt paper is properly applied to a leaf surface the actual water loss can be obtained. A number of investigators have used small glass plates to cover the cobalt papers in protecting from atmospheric moisture, and to hold the papers in place on the leaf to be tested. Sayre (12) used celluloid instead of glass. The cobalt paper was cut in circular areas with a punch $\frac{15}{32}''$ in diameter. The celluloid was cut in strips $\frac{5}{8}''$ x $1\frac{1}{2}''$. The cobalt paper was then fastened at each end and on the same surface of the strips by means of gummed reënforcements for notebook paper. These were of greater diameter than the width of the strips, so extended over the sides and end. A reënforcement was moistened and applied near one end of the strip, the perforation being covered by the celluloid. While still moist the strip

*The following workers have contributed to our knowledge of water loss from various species: Livingston (9), Shreve (17), Trelease (20), Meyer (12 and 13), Shive and Martin (16), Cribbs (4 and 5), McGinnis and McDougall (11), Bakke (1 and 3), Delf (6), Kiesselbach (8), Rosenberg (15), and others. With the exception of Kiesselbach, these workers used Stahl's (19) Cobalt Chloride Method, the same as improved by Livingston (9), Livingston and Shreve (10) and by Sayre (12).

was inverted, cobalt paper placed opposite the perforation in reenforcement and a dry reenforcement placed over the paper so that the dry gummed surface was in contact with the moist gummed surface projecting over the edges. The gummed surfaces were pressed tightly together. These held the cobalt paper in position with only the one surface exposed, which was to be placed next to the leaf, and the other surface could be seen through the celluloid. After cobalt paper was attached to both ends of strip in the above manner, the strip was folded along the short axis through the center. This then made a clip which could be readily clamped on a leaf with a hygrometric paper exposed to each surface. In this work the clips were attached to a leaf surface by means of small clamps (Denison Card Holder, No. 42). The hook at the end was convenient for attaching a slip of paper with number of the leaf and time at which the clip was applied. Fifty or sixty clips were made so that time would not be lost in waiting for them to dry in a desiccator. The clips were kept in desiccators made of wide-mouthed bottles, of convenient size for carrying, with anhydrous calcium chloride. These clips were used until they became soiled or wet. The desiccating process can be greatly speeded up by placing the bottles in bright sunlight or near a fire. As color standards, a paper may be kept in a small desiccator for the blue color. For the pink standard a clip which has been in contact with a leaf surface until a full pink color has appeared, may be carried about on a leaf, or in a bottle.

The paper used in collecting the data given below was standardized to .05981 gram of water per 100 square centimeters. That is, it took .05981 gram of water to change the blue (dry) cobalt chloride paper to a full pink color. So, if it takes 1 minute to change the blue to pink, the grams of water vapor absorbed per 100 square centimeters in one hour would be 60 times .05981 gram. Meyer's (12) formula was used in making the calculations. It is as follows:

$$\frac{.05981 \times 3600 \text{ (Sec. in one hour)}}{\text{T (Time of color change)}} = \text{G (Grams of water vapor).}$$

In each case the wet and dry bulb temperatures were taken in order that the relative humidity might be determined. The thermometers were kept in a shaded place as near the leaves being tested as was possible. Shreve (17) showed that temperature of the air immediately surrounding the leaf may be safely used instead of the temperature of the clip itself. Leaves in good condition as far as could be determined were selected in every case except where indicated. In practically all cases five readings were taken at a single time, each on different leaves, and the time of color change averaged for each surface. So that in the following lists and graphs the time of color change indicated is an average for a given surface, and not for a single leaf or a single reading. The time of change has also been standardized for a temperature of 20 degrees C. In doing this Livingston's and Shreve's (10) table was used.

Bakke (1) pointed out the fact that the only external environmental factor directly affecting water loss from a leaf surface by cobalt chloride paper is temperature. This can be standardized to a given degree by Livingston's and Shreve's (10) table.

The relative humidity may have an effect through the layer of air imprisoned between the leaf surface and the cobalt paper. This effect must be very small since the moisture in this layer is absorbed almost instantly and the relative humidity is 0 in a very short time after the clip is applied.

The direct effect of light is small since but little light can pass through the cobalt paper. The relative humidity and light intensity may have a far reaching indirect effect. The direct effect of air currents is also removed. Some of the other factors which may have effect upon water loss have been pointed out by Kiesselbach (8) and Cribbs (4 and 5).

The cobalt chloride method of measuring water loss measures the water vapor given off at a particular instant, and is not measuring accumulative quantities, as does the potometer method. For this reason it is not safe to compare the two means of determination. In the potometer method light, relative humidity and wind have a direct effect on the amount of water lost. Because of these differences Dr. E. N. Transeau suggested to the writer the term "Standard Water Loss" from the leaf surface, as being the water loss measured by the cobalt chloride method.

The chief sources of error in the cobalt chloride method are:

1. The hygrometric paper absorbs some moisture from the atmosphere during transfer from the desiccator to the leaf. In every case this transfer was accomplished as quickly as possible, and took but a few seconds.

2. There may be a source of error in determining when to take the reading. This difficulty may be, at least partly, removed by having color standards as suggested.

3. Lateral leakage from surrounding air may also be a source of error. This error seems to be quite small, for in a number of instances, usually on upper surfaces, the test papers remained unchanged for two hours.

4. Pressure of the clip on the leaf surfaces may cause some change in size of the opening of the stomata.

5. Average leaves may not be selected for the tests. However, as tests were made on five leaves each time and an average taken for the standard water loss, it is believed that most of this source of error is removed.

Measurements of Water Loss.

Standard water loss data was collected on the following 123 species during the fall of 1925, spring, summer and fall of 1926. Excepting tests for diurnal rates, all readings were taken between the hours of 10:00 A. M. and 1:30 P. M. during which time the stomata were expected to be open and the maximum rate of standard loss taking place. As some of the series of readings later showed, this is not always the case. The maximum rate sometimes occurred early in the day, as shown by the diurnal study. Shreve (18) found this to occur among some desert species. Although the readings do not necessarily represent the maximum rate of standard water loss, they still retain a certain value as a survey.

This list contains plants from a wide range of environmental conditions. Some examples are as follows:

Sphagnum Bog—*Vaccinium*, *Menyanthes*, *Sarracenia*, *Decadon*, *Alnus*, *Hibiscus*, and *Rhus Vernix;* Swamp—*Cephalanthus*, *Sium*, *Quercus palustris*, *Rosa carolina*, *Ilex*, *Alisma*, *Iris*, *Glyceria*, *Impatiens*, etc.; Aquatic—*Polygonum amphibium*, *Typha*, *Sagittaria*, *Dianthera*, etc.; Flood plain—*Salix*, *Aesculus*, *Allium*, *Angelica*, *Arctium*, *Asimina*, *Celtis*, *Prunus* and *Urtica;* River Bank—*Ambrosia*, *Elymus*, *Platanus*, etc.; Talus slope—*Sambucus racemosa*, *Epigea*, *Epipactus*, *Gaulthera*, *Cypripedium*, *Rhododendron* and *Betula;* Ledge—*Sullivantia* and *Polypodium;* Plains—*Buchloe;* Prairies—*Silphium laciniatum;* Agricultural plants—*Zea*, *Solanum tuberosum*, *Bromus*, and *Phleum;* "Weeds"—*Amaranthus*, *Xanthium*, *Chenopodium*, *Convolvulus*, *Abutilon*, *Lactuca*, *Arctium*, *Setaria*, *Digitaria*, *Taraxacum*, *Polygonum virginianum*, *Leonurus*, *Erigeron*, *Cirsium*, and *Ambrosia*.

TABLE I.

MEASUREMENTS OF WATER LOSS.

NAME OF PLANT	Date	Temp. of air in Degrees C.	Av. No. of Secs. for Upper Surface	Av. No. of Secs. for Lower Surface	Corrections made for Temp. (Upper)	Corrections made for Temp. (Lower)	Grs. of Water Lost Per Hour (Upper)	Grs. of Water Lost Per Hour (Lower)	Time of Reading	Relative Humidity
Abies Cilicica Carr.	4-21'26	17.7	824	1360	716.5	1182.6	.3	.182	12:30	41
Abutilon Theophrasti Medic.	6-25'26	26.9	158	44	239.3	66.6	.89	3.23	11:40	52
Acer platanoides L.	10-15'25	14.4	1605	247	1132.3	173.9	.18	1.23	12:30	89
Acer rubrum L.	7-16'26	26.6	1780	116	2656.7	173.1	.081	1.243	12:30	56
Acer saccharinum L.	10- 8'25	14.4	1995	150	1404.9	105.6	1.532	2.038	12:25	62
Acer saccharum L.	5-19'26	18.0	2940	1344	2601.7	1189.3	.082	.181	11:40	82
Aesculus glabra Willd.	5-25'26	18.6	3624	2004	3324.7	1838.5	.0647	.117	12:35	89
Argopyron repens (L.) Beauv.	7-14'26	24.4	76	89	98.7	115.5	2.181	1.864	12:49	43
Alisma Plantago-aquatica L.	6- 1'26	26.6	60	60	65.9	65.9	3.267	3.267	12:55	75
Allium Tricoccum Ait.	4-10'26	13.3	642	383	419.6	250.3	.513	.862	12:11	55
Alnus rugosa (Du Roi) Spreng.	7-15'26	23.8	......	840	....	1063.2	....	.202	11:40	58
Ambrosia trifida L.	7-14'26	19.4	168	95	161.5	91.3	1.333	2.358	10:45	67
Amaranthus retroflexus L.	6-26'26	26.1	47	49	68.1	71	3.162	3.032	12:05	57
Angelica atropurpurea L.	5- 6'26	26.6	589	59	879	88	.244	2.446	1:25	35
Arctium minus Bernh.	5-31'26	24.7	474	108	632	144	.3406	.149	11:50	83
Asimina triloba Dunal.	8- 6'26	28.6	1440	125	2400	208.3	.0897	1.033	10:20	80
Aspidium cristatum (L.) Sw.	6-19'26	19.44	492	177	473	170.1	.455	1.265	11:45	67
Aspidium marginale (L.) Su.	4-10'26	14.1	2322	1564	1601.3	1078.5	.134	.199	11:05	46.5
Barbarea vulgaris R. Br.	4-14'26	17.7	149.3	97.5	131.1	85.5	1.642	2.518	12:00	9
Berberis thunbergii D. C.	7- 3'26	30.0	1428	402	2596.3	730.9	.082	.294	11:52	58.5
Betula lenta L.	7- 8'26	25.2	520	38.3	712.2	52.4	.302	4.10	12:05	77
Bromus inermis Leyss.	7- 1'26	31.1	955	3172	1836.3	6100	.117	.035	12:35	39.5
Buchloe dactyloides (Nutt) Engelm.	7-12'26	26.1	1745	1745	2528.9	2528.9	.085	.085	10:33	54
Cannabis sativa L., (Male)	8-26'26	25.2	868	88	1189	120.5	.0181	1.786	11:30	75
Cannabis sativa L. (Female)	8-26'26	25.2	570	91	780.8	124.6	.0275	1.728	11:30	75
**Carica papaya* Linn.	7-20'26	34.4	......	662	....	1539.5	....	.167	10:45	39
Castanea dentata (Marsh) Borkh.	7- 8'26	26.3	520	296.6	764.7	436.4	.281	.493	12:55	71
Catalpa bignonioides Walt.	7-13'26	20.5	2116	311	2181.4	320.6	.0987	.671	11:45	74
Celtis occidentalis L.	8- 6'26	29.7	1338	132	2389.2	235.7	.09	.913	11:00	81
Cephalanthus occidentalis L.	6-22'26	23.3	1608	37	1960.9	45.1	.109	4.774	11:15	64
Chenopodium album L.	6-25'26	28	150	128	241.9	206.4	.89	1.04	12:13	49
Cirsium arvense (L.) Scop.	6-24'26	27.2	518	60	796.9	92.3	.271	2.33	11:30	51
Convolvulus sepium L.	6-25'26	28.6	130	146	216.6	243.3	.994	.884	1:15	40
Corylus americana Walt.	6-23'26	26.3	1614	59	2375	86.7	.090	2.48	12:15	52
Crataegus sp.	5-13'26	18.8	2400	104	2242.9	97.1	.095	2.21	12:30	87
Cypripedium hirsutum Mill.	7- 9'26	26.9	339	71	513.6	107.5	.419	2.002	11:20	85
Decadon verticillatus (L.) Ell.	7-15'26	25.2	2755	77	3773.9	105.4	.057	2.042	12:55	60
Dianthera americana L.	7-14'26	20.83	92	181	96.8	190.5	2.22	1.13	10:23	57.5
Digitaria sanguinalis (L.) Scop.	6-25'26	27.7	924	304	1466.6	482.5	.146	.446	2:30	46.5
Elymus virginicus L.	7-22'26	37.2	475	....	1283.7	....	.167	....	12:05	43.5
Epigaea repens L.	7- 9'26	26.6	155	64	231.3	95.5	.930	2.25	11:20	87

*Growing in Greenhouse.

TABLE I—Continued.

Name of Plant	Date	Temp. of air in Degrees C.	Av. No. of Secs. for Upper Surface	Av. No. of Secs. for Lower Surface	Corrections made for Temp. (Upper)	Corrections made for Temp. (Lower)	Grs. of Water Lost Per Hour (Upper)	Grs. of Water Lost Per Hour (Lower)	Time of Reading	Relative Humidity
Epipactus sp.	7- 9'26	27.7	500.6	66	794.6	104.7	.270	2.05	12:50	70
Equisetum arvense L.	7- 1'26	30.2	98	250	181.4	462.9	1.175	.465	12:15	34
Erigeron annuus (L.) Pers.	6-23'26	27.5	3372	2844	5268.7	4443.7	.040	.048	12:15	57.5
Eupatorium perfoliatum L.	6-23'26	25	1884	47	2595.9	63.5	.084	3.39	1:10	56
Fraxinus americana L.	10-14'25	13.3	2435	170	1591.5	111.1	.135	1.938	11:37	94
Gaulthera procumbens L.	7- 9'26	26.6	943.3	71.6	1407.9	106.8	.152	2.016	10:13	87
Gleditsia triacanthos L.	10-13'25	15.56	230	133	172.9	100	.1245	2.153	12:30	68
Glyceria nervata Trin.	7- 2'26	30.28	50	672	92.4	1244.4	2.33	.173	12:55	48
Glyceria septentrionalis Hitchc.	7- 2'26	30.00	54	90	98.1	163.6	2.194	1.316	12:20	57
Hepatica acutiloba D. C.	4-12'26	6.9	3121	947	1333.7	404.7	.161	.532	1:38	70
Hibiscus moscheutos L.	7-15'26	23.89	......	168	....	212.6	....	1.012	11:26	58
Ilex verticillata (L.) Gray.	6-19'26	19.4	2652	128	2550	123	.084	1.75	....	67
Impatiens biflora Walt.	7- 2'26	30.56	54	33	101.8	62.2	2.115	3.46	12:05	60.5
Iris versicolor L.	6-22'26	23.6	45	56	56.2	70	3.83	3.075	11:30	60.5
Juglans nigra L.	7- 3'25	30.8	2460	1116	4641.5	2105.6	.046	.102	12:25	54
Kalmia latifolia L.	7- 9'26	26.6	788.3	63.6	1776.5	94.7	.121	2.273	10:00	87
Lactuca scariola integrata Gren. and Godr.	6-21'26	25.8	1212	165	1731.4	235.7	.124	.913	10:30	64
Leersia oryzoides (L.) Su.	7-22'26	27.7	607	93	963.4	147.6	.223	1.458	10:15	78
Leonurus cardiaca L.	6-21'26	26.1	1818	203	2634.7	294.4	.081	.731	10:50	64
Lonicera sp.	5-14'26	17.2	1644	59	1381.5	49.5	.155	4.349	12:20	72
Lysimachia nummularia L.	4-15'26	4.4	1103	509	396.7	183	.542	1.176	12:10	61
Malva rotundifolia L.	10- 7'25	23.06	365	123	439.7	148.1	.4896	1.453	1:05	65
Maclura pomifera (Raf.) Schn.	8- 6'26	31.6	1572	58	3144	116	.068	1.856	12:31	65
Menyanthes trifoliata L.	7-16'26	23.33	320	84	390.2	102.4	.551	2.102	10:05	72
Mitchella repens L.	4-13'26	8.8	3492	632	1695.1	306.7	.127	.702	12:40	53
Nepeta cataria L.	4-14'26	17.7	392	137	340.8	119.1	.631	.180	12:15	9
Nepeta hederacea (L.) Trevisan	4- 7'26	17.5	908	92	776	78.6	.277	2.739	12:25	61
Oenothera biennis L.	6-21'26	26.9	1020	958	1545.4	1451.5	.139	.148	11:15	61.5
Ophioglossum vulgatum L.	6-30'26	28.3	370	142	606.5	232.1	.355	.927	10:30	66
Osmunda cinnamomea L.	7-16'26	25.8	872	101	1245.7	144.2	.172	.149	12:20	53.5
Pastinaca sativa L.	10-23'25	15.00	667	102	486.8	74.4	.442	2.89	12:15	39
Phleum pratense L.	7-14'26	23.89	138	143	174.6	181	1.233	1.189	12:40	48
Picea Abies (L.) Karst.	4-27'26	12.2	1402	1402	854	854	.252	.252	12:45	43
Pinus austriaca Hoss.	5-19'26	17.78	261	261	226.9	226.9	.948	.948	12:20	79
Pinus contorta Dougl.	4-23'26	18.8	252	210	233.3	185.1	.9229	1.163	12:30	58
Pinus rigida Mill.	4-24'26	14.4	255	286	179.5	201.4	1.199	1.069	12:30	72
Pinus strobus L.	4-23'26	18.8	882	890	816.6	824.1	.2636	.261	11:50	58
Pinus sylvestris L.	4-20'26	13.3	892	988	583	645.7	.369	.333	12:30	32
Plantago lanceolata L.	10- 8'26	14.4	66	71	464	50	.464	4.306	12:22	62
Plantago major L.	10- 8'25	14.4	121.6	60	85.6	42.2	2.503	5.102	12:50	62
Platanus occidentalis L.	8- 6'26	31.3	1434	64	2811.7	125.4	.076	1.717	11:58	64
Polygonum amphibium L.	7-15'26	22.7	50	50	58.8	58.8	3.661	3.661	11:15	58
Polygonum virginianum L.	7-12'26	28.8	2675	124	4533.8	210.1	.047	1.024	12:45	70
Polypodium vulgare L.	4-10'26	13.8	3459	1563	2337.1	1056	.092	.203	12:45	51.5
Polystichum acrostichoides (Michx.)	4-12'26	6.9	4615	726	1972.2	310.2	.109	.694	1:32	71
Polytrichum ohioense R. & C.	7- 2'26	30.5	25	25	47.1	47.1	4.571	4.571	12:40	42.5
Populus deltoides Marsh.	10-15'25	15.0	455	210	332.1	145.9	.648	1.475	12:15	89
Potentilla canadensis L.	6-23'26	26.1	493	33	714.3	47.8	.301	4.504	12:50	48
Prunus serotina Ehrh.	5- 7'26	27.7	......	130	....	206	....	1.045	12:10	31

TABLE I—Continued.

Name of Plant	Date	Temp. of air in Degrees C.	Av. No. of Secs. for Upper Surface	Av. No. of Secs. for Lower Surface	Corrections made for Temp. (Upper)	Corrections made for Temp. (Lower)	Grs. of Water Lost Per Hour (Upper)	Grs. of Water Lost Per Hour (Lower)	Time of Reading	Relative Humidity
Quercus bicolor Willd	6-18'26	25.2	1812	876	2482.1	1200	.086	.179	11:45	77
Quercus palustris Muench	6-23'26	26.1	1848	112	2678.2	162.3	.080	1.326	12:00	57
Rhododendron maximum L	7- 7'26	22.2	1956	105.6	2248.2	121.3	.095	1.775	10:20	86
Rhus Vernix L	7-15'26	24.4	3001	282	3897.3	366.2	.055	.587	12:32	48
Rosa carolina L	6-17'26	29.4	1515	60	2657.8	105.2	.081	.204	1:00	63
Rubus occidentalis L	5-20'26	16.9	4020	93	3322.3	77.6	.064	2.774	12:45	62
Rumex altissimus Wood	7-12'26	28.6	206	133	343.2	221.6	.627	.971	12:30	72
Sagittaria sp	6- 1'26	22.2	112	82	128.7	94.2	1.673	2.285	12:40	73
Salix babylonica L	10-14'25	13.8	1585	171	1070.9	115.5	.201	1.864	12:30	100
Salix discolor Muhl	6-18'26	22.5	92.8	53.2	107.9	61.8	1.995	3.484	12:00	63
Salix nigra Marsh	7-22'26	29.1	172	60	296.5	103.4	.726	2.082	11:00	70
Sambucus canadensis L	6-22'26	23.6	3084	44	3855	55	.055	3.914	11:45	58.5
Sambucus racemosa L	7- 7'26	25.2	2520	2136	3452.1	2926	.0623	.735	12:45	58
Sarracenia purpurea L	7-16'26	23.3	512	454	624.3	553.6	.344	.388	10:20	66
Setaria italica (L.) Beauv	7-14'26	21.9	960	1331	1078.6	1495.5	.199	.143	12:00	54
Silphium laciniatum L	7-12'26	25.2	113	124	154.7	169.8	1.391	1.268	10:10	54.5
Silphium perfoliatum L	7- 1'26	29.4	1788	1200	3136.8	2105.2	.068	.102	11:20	41.5
Sium cicutaefolium Schrank	6-18'26	22.2	312	60	358.6	68.9	.600	3.125	11:05	69
Solanum Dulcamara L	10-24'25	15.0	......	483	....	352.5	....	.610	12:30	39
Solanum tuberosum L	6-26'26	26.6	235	258	350.7	385	.613	.559	10:45	54
Sullivantia Sullivantii (T.& G.) Britton	7- 8'26	25.5	615	180	8541	250	.025	.845	11:45	78
Taraxacum officinale Weber	7- 3'26	31.1	612	92	1176.9	176.9	.182	1.217	1:15	52
Typha angustifolia L	7-16'26	25.5	115	216	159.7	300	1.348	.717	11:30	64
Typha latifolia L	5-31'26	26.6	64	52	95.5	77.6	2.254	2.774	12:30	83
Ulmus americana L	10-13'25	13.8	1330	130	904.7	88.4	2.379	2.435	12:12	77
Urtica gracilis Ait	5-20'26	16.6	2076	66	1674.1	53.2	.128	4.047	1:15	64
Vaccinium macrocarpon Ait	7-16'26	26.6	635	108	947.7	161.2	.227	1.335	12:50	54
Verbascum Thapsus L	3-25'26	5.5	1237	455	479.4	176.3	.449	1.221	1:15	92
Vinca minor L	3-24'26	16.1	4152	203	3243.7	158.5	.066	1.358	12:11	77
Vitis cordifolia Michx	5-26'26	20.5	42	384	43.2	395.8	4.984	.544	1:00	55
Xanthium sp	7-14'26	25.0	91	63	122.9	85.1	1.751	2.530	1:04	41
Yucca sp	3-29'26	9.7	4130	3702	2128.8	1908.2	.1011	.1128	1:28	58.5
Zea mays L	6-25'26	24.1	139	122	178.2	156.4	1.208	1.376	10:30	61

A study was made of the standard loss from evergreen plants. The readings were taken before growth had started in the spring. The leaves were approximately one year old.*

*The averages which follow were obtained first by averaging the standard loss for the upper and lower surfaces of the leaves as given in the above list of plants (i. e. these quantities of water vapor represent the sum of the loss from 50 sq. cm. of upper surface and 50 sq. cm. of the lower surface). Then these averages were averaged for the following groups.

I. Spermatophytes.

A. Gymnosperms.

1. *Abies Cilicica*
2. *Picea abies*
3. *Pinus austriaca*
4. " *contorta*
5. " *rigida*
6. " *strobus*
7. " *sylvestris*

The average standard loss for this group was .5481 gm. The greatest loss was from *P. rigida*—1.134 gm. The smallest was from *A. Cilicica*—.241 gm.

B. Angiosperms—(Leaves had passed through the winter. Exact age was not known.)

1. *Barbarea vulgaris*
2. *Lysimachia numularia*
3. *Mitchella repens*
4. *Nepeta Cataria*
5. *Nepeta hederacea*
6. *Verbascum Thapsus*
7. *Vinca minor*
8. *Yucca* sp.

The average for the group was .8523 gm. *Barbarea* was highest—2.08 grams, and *Yucca* was lowest—.1065 gm.

II. Pteridophytes.

1. *Aspidium marginale*
2. *Polypodium vulgare*
3. *Polystichum acrostichoides*

The average for the group was .2401 gm. *Polystichum* was highest—.4015 gm. *Polypodium* lowest—.1525 gm.

Some readings were taken on a sugar maple and two pines growing near one another. The readings were taken within one hour and on the same day. The maple leaves were approximately 20 days old and the pine leaves about 1 year old. The results are as follows:

Acer saccharum	.104 gm.
Pinus sylvestris	.110 "
Pinus austriaca	.948 "

In order to get a comparison between the standard loss for corn, the potato and some common "weeds," growing along beside the corn and potato, the following data were collected:

1.	*Abutilon Theophrasti*	2.065 grams
2.	*Amaranthus retroflexus*	1.848 "
3.	*Chenopodium album*	2.889 "
4.	*Convolvulus sepium*	2.132 "
5.	*Digitaria sanguinalis*	.295 "
6.	*Setaria italica*	.171 "
7.	*Xanthium* sp	2.14 "
8.	*Solanum tuberosum*	1.361 "
9.	*Zea mays*	1.786 "

McGinnis and McDougal (11) made a number of similar comparisons of several "weeds" with corn, using the cobalt chloride method as developed by Livingston and Shreve (10). Their plants were of necessity grown in the greenhouse and data were obtained during the months of February, March and April. The writer took a series of readings in August on a single *Zea* plant and a similar series simultaneously on an *Amaranthus* plant, growing near the corn. Fig. 1 shows the results graphically.

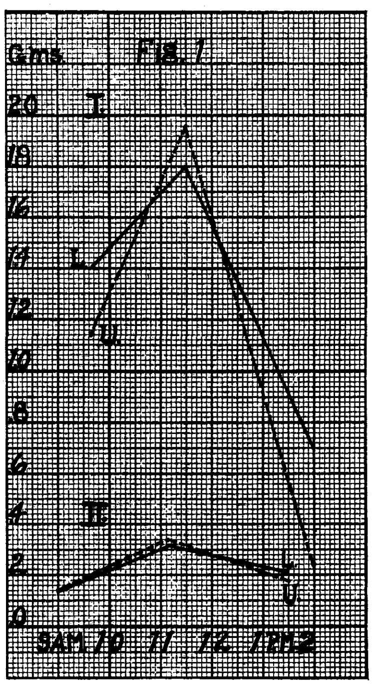

Fig. 1. I. Graph showing the standard water loss for the upper (U) and lower (L) surfaces of *Amaranthus retroflexus* leaves. II. Graph showing the standard water loss for the upper (U) and lower (L) surfaces of *Zea mays* leaves. Readings on both plants were taken simultaneously.

An effort was made to test out the difference in standard loss of rolled and non-rolled leaves of the same species. The two bunches of *Elymus virginicus* selected were growing within a few feet of each other on a river bank. One bunch showed rolled leaves and the other did not. The leaves tested were not on the same plant but on different plants in each cluster. The results are as follows:

Rolled leaves were losing................ .167 gram
Unrolled leaves were losing.............1.696 grams

Bakke and Livingston (3) pointed out the fact that water loss is different for leaves occupying different positions on the same plant. This has been confirmed in the case of a large specimen of *Ulmus americana.* Readings were taken at an altitude of approximately 40 feet, and others on leaves which could be reached while standing on the ground. The lower readings were started at 11:45 and the upper at 12:00. The leaves were more or less shaded in both positions. The tests were made in August. The tree apparently had an abundant water supply as it was growing on a river bank. No satisfactory color change was obtained in either upper surface. In the upper position only one paper changed color on the lower surface after an exposure of 50 minutes. The other papers were left on for 1 hour and 20 minutes without change. In the lower position, papers on the lower surfaces changed in the average time of 38 minutes 24 seconds. The standard water loss was .0401 gm. per 100 square centimeters in one hour at a temperature of 20 degrees C. Calculations for the upper position were not made because of unsatisfactory color change. The rate for the leaves in the higher position was evidently much lower.

A number of readings were taken simultaneously on young and mature leaves in order to get a comparison. The results were as follows:

	YOUNG	MATURE
1. *Silphium perfoliatum*..........	.2085 gm.	.788 gm.
2. *Corylus americana*.............	.285 "	1.2865 "
3. *Arctium minus*................	.5235 "	3.5955 "
4. *Cephalanthus occidentalis*.......	.193 "	1.239 "
5. *Chenopodium album*...........	.9665 "	2.8895 "
6. *Convolvulus sepium*............	.939 "	2.1325 "
7. *Sarracenia purpurea*...........	.118 "	.732 "
8. *Typha latifolia*................	4.816 "	2.51 "

It is interesting to note that Typha latifolia is the only species examined in which the young leaves were simultaneously losing more water than the mature leaves. Meyer (13) has been able to express more juice from mature leaves than from young.

A series of readings were made on *Acer saccharum*, *Rosa carolina* and on *Catalpa bignonioides*, at certain intervals during the summer. The leaves were marked when the first reading was made. The same leaves were tested each time, excepting in the last reading on the *Acer* all the marked leaves had disappeared except two. Others were selected which were approximately in the same position. Also all but one of the tagged leaves of Rosa had disappeared by the time of the second reading.

The readings on *Rosa* were made first on May 17, and showed a standard loss of .933 gm. One month later, at the same time of day, readings were again taken. The loss then was .141 gm., showing a decrease of .792 gm. per unit area for the more mature leaves.

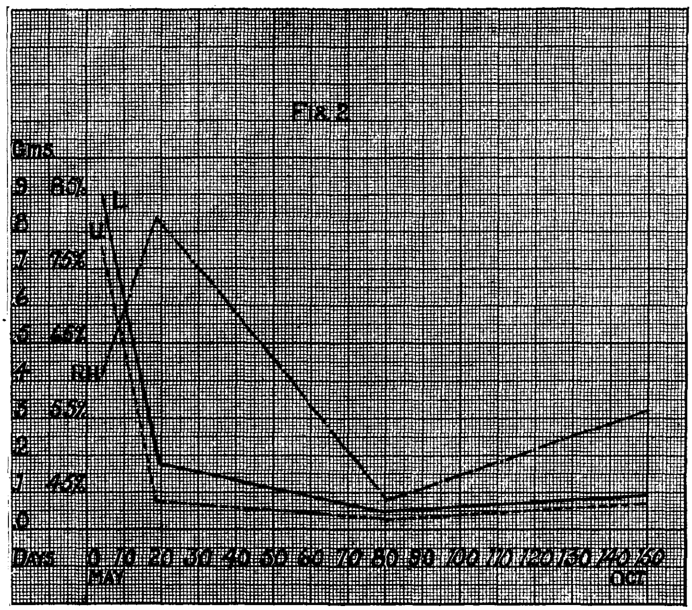

Fig. 2. Graph showing standard water loss from leaves of *Acer saccharum* from the time they were unrolling from the buds until they were approximately 150 days old. L, lower surface. U, upper surface. R. H., relative humidity.

On July 13 the first readings were taken on *Catalpa*. The loss was found to be .4475 gm. On August 31 readings were again taken on the same leaves at the same time of day. The result obtained this time was .2559 gm., or .1916 gm. decrease for the older leaves.

On May 4 readings were started on *Acer saccharum*. The leaves were just unrolling at this time. Three other readings were taken during the summer and autumn. The graph, Fig. 2, shows the results.

While working with very young leaves it was found that several, notably *Convolvulus*, *Psedera quinquefolia* (L) Greene and *Vitis cordifolia* Michx. lost water more rapidly along the midrib than on the remainder of the leaf. This was determined by the fact that a pink streak appeared in the cobalt paper which was directly over the midrib or a large vein. The remainder of the paper continued blue for some time.

Starting at 12:45 P. M., on July 7, a series of tests were made extending through 24 hours on *Sambucus racemosa.* The plant was growing on a talus slope, east exposure, very sandy soil, and protected by a high, cave-like cliff. There was a large spring a few feet away, so it likely had a plentiful

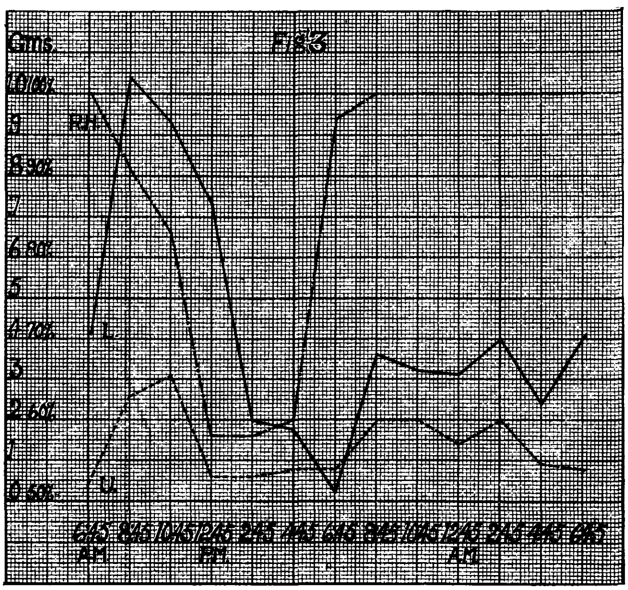

Fig. 3. Graph showing standard water loss for *Sambucus racemosa* during 24 hours. R. H., relative humidity. U, upper leaf surface. L, lower leaf surface.

water supply. The leaves were tagged and an area carefully marked on which the readings were taken each time. The readings were taken at two hour intervals. The results are graphically shown in Fig. 3.

Another series through 24 hours was obtained for *Catalpa bignonioides.* Readings were taken at intervals of 2 hours excepting from 7:45 A. M. to 3:45 P. M., during which time they were taken every hour. Five leaves, in apparently good condition, were selected and tagged as for *Sambucus.* Fig. 4 is a graph of the results obtained.

Peirce (14) states that many plants living in swamps and swampy places have constantly open stomata, and cites willows as a note-worthy example. Haberlandt (7) says "In many

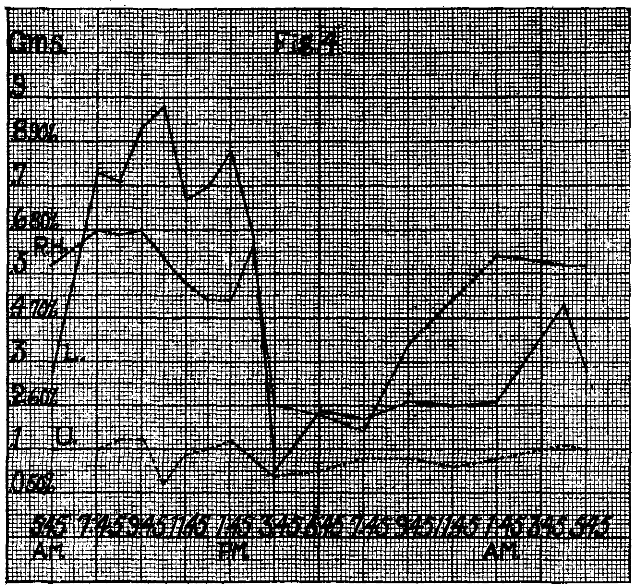

Fig. 4. *Catalpa bignonioides* standard water loss for 24 hours. R. H., relative humidity. U., upper leaf surface. L., lower leaf surface.

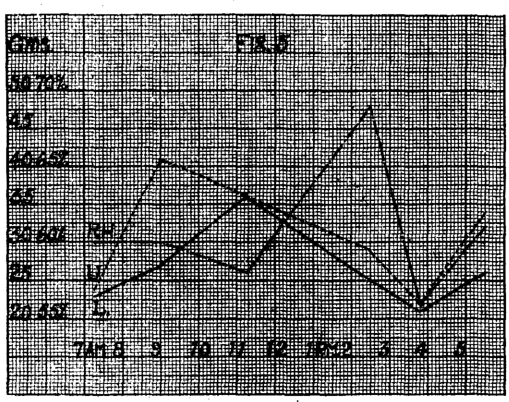

Fig. 5. *Polygonum amphibium* standard water loss. R. H., relative humidity. U., upper leaf surface. L., lower leaf surface.

plants the stomata lose their power of adjustment more or less completely, or at any rate become incapable of closing tightly after a certain age. This physiological degeneration of the stomata takes place at a comparatively early age in floating and other aquatic plants, and also in a number of shade-loving hygrophytes." Delf (6) refers to such instances when considering Rosenberg's (15) work on the halophytes.

In order to investigate some of these aquatic and moist soil forms a series of readings were made, beginning first with *Polygonum amphibium*. The time of the readings range from 7:45 A. M. to 5:30 P. M., and were taken at two hour intervals.

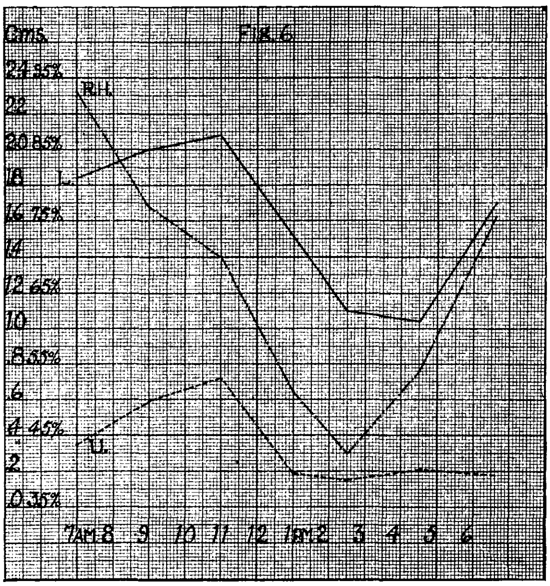

Fig. 6. *Salix nigra* standard water loss. R. H., relative humidity. U., upper leaf surface. L., lower leaf surface.

Fig. 5 shows the results. Series were taken on *Salix nigra*, *Dianthera americana*, *Hibiscus Moscheutos* and *Typha angustifolia*. The *Salix* and *Dianthera* were growing in water along the edge of a river; and the *Polygonum Hibiscus* and *Typha* were growing in water along the edge of a Sphagnum bog. Figs. 6, 7, and 8 respectively show the results.

Summary and Conclusion.

1. The data collected on the list of plants holds good only for the time and conditions listed. The time of day, age of plant, position of leaves, and habitat have a great deal to do with the standard loss. Other unknown factors may also cause a variation.

2. The average standard water loss for the whole list of 123 species, on which data was collected, is 1.15012 grams of water vapor in 1 hour for a leaf surface of 100 square centimeters. This and the following amounts are averages for both leaf surfaces.

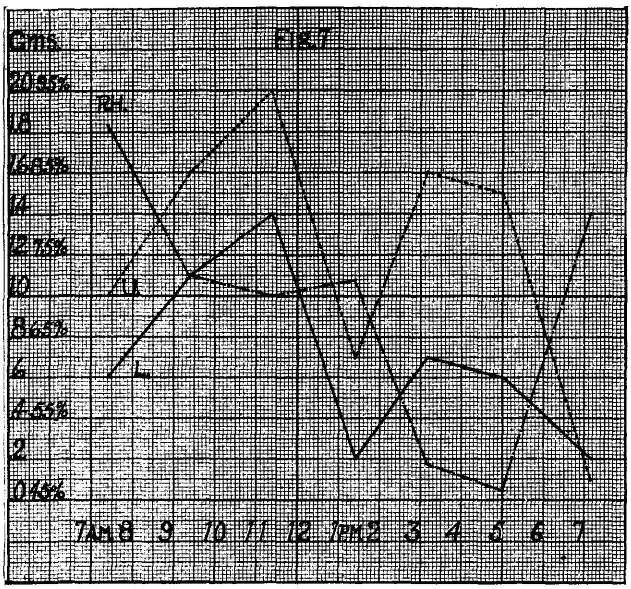

Fig. 7. *Dianthera americana* standard water loss. R. H., relative humidity. U., upper leaf surface. L., lower leaf surface.

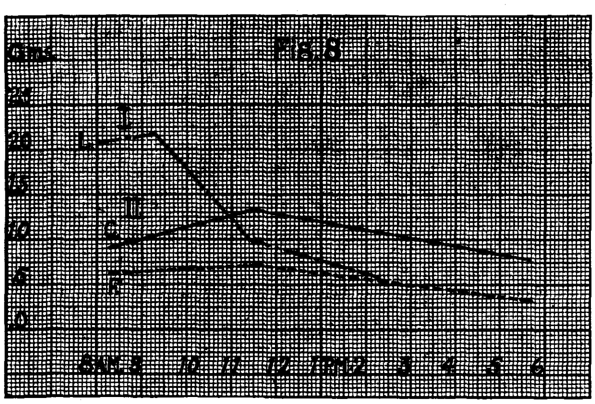

Fig. 8. I. *Hibiscus Moscheutos* standard water loss. Graph shows loss for lower surface only. II. *Typha angustifolia* standard water loss. C., curved surface. F., flat surface of leaves.

3. The average standard water loss, per hour for 100 square centimeters, for each group tested is as follows:

			No. Tested
I.	Spermatophytes	1.2146 gms	114
	A. Gymnosperms	.605 gm	7
	B. Angiosperms	1.2545 gms	107
	1. Grasses*	.8256 gm	11
II.	Pteridophytes	.4564 gm	7
III.	Bryophytes†	4.571 gms	1

4. The average rate of standard water loss for each of 8 associations is as follows:

		No. Tested
Swamp	1.9644 gms	10
Bog (acid)	.6413 gm	9
Pond and Lake Margin	2.2965 gms	4
River Margin	1.9395 gm	3
River Bank	.9413 gm	3
Flood Plain (mature)	.7549 gm	8
Ledge association	.293 gm	2
Talus slope	1.2218 gms	8

5. The following plants showed the greatest standard loss:

Polytrichum ohioense	4.571 gms.
Plantago major	3.802 "
Polygonum amphibium	3.661 "
Iris versicolor	3.452 "
Alisma Plantago-aquatica	3.267 "

6. The following is a list of plants showing lowest water loss:

Erigeron annuus‡	.04 gm.
Juglans nigra	.074 "
Bromus inermis	.076 "
Elymus virginicus	.083 "
Buchloe dactyloides	.085 "
Silphium perfoliatum	.085 "
Aesculus glabra	.09 "

7. Tests on evergreen leaves, before growth had started in the spring, showed the following results:

Angiosperms	.8523 gm.
Gymnosperms	.5481 "
Pteridophytes	.2401 "

*This includes swamp as well as plain form).

†*Polytrichum ohioense*, growing in a very moist location.

‡This plant was growing in a very dry location. Tests were made on another plant growing at the edge of a swamp. The soil was very wet. The standard loss in this instance was .37805 gm. per 100 sq. cm.

8. Tests for comparison between *Acer saccharum*, *Pinus austriaca* and *P. sylvestris*, under apparently the same external environmental conditions, showed that the year old pine needles were losing more water than the leaves of the maple which were about 20 days old.

9. Tests on *Abutilon*, *Amaranthus*, *Chenopodium*, *Convolvulus*, *Digitaria*, *Setaria*, *Xanthium*, *Solanum* and *Zea*, all growing near one another in the same field, showed an average standard loss of 1.631 gms. The average for the weeds alone was 1.6485 gms. This includes *Digitaria* and *Setaria* which are very slow water losers. The average for the corn and potato was 1.5735 gms.

10. Graphic results of a series of readings on *Amaranthus* and *Zea*, growing side by side, shows that the pigweed loses nearly 6 times as much water as the corn per 100 square centimeters. This is just considering the maximum loss for each. The graph also shows that the time of maximum loss may vary for different species.

11. The following common "weeds," selected at random, showed an average standard loss of 1.1425 gms.: *Amaranthus*, *Xanthium*, *Chenopodium*, *Convolvulus*, *Abutilon*, *Lactuca*, *Arctium*, *Setaria*, *Digitaria*, *Taraxicum*, *Polygonum virginianum*, *Leonurus*, *Erigeron*, *Cirsium* and *Ambrosia*. Four agricultural plants showed a standard loss of 1.1085 gms. They were as follows: *Zea*, *Solanum tuberosum*, *Bromus* and *Phleum*.

12. Tests on rolled and unrolled leaves of *Elymus* showed that the unrolled leaves were losing over 10 times as much water as the leaves which were rolled.

13. Leaves of *Ulmus*, at an approximate altitude of 40 feet, were losing less water than those near the ground.

14. Very young leaves of *Silphium perfoliatum*, *Corylus*, *Arctium*, *Cephalanthus*, *Chenopodium*, *Convolvulus*, and *Sarracenia*, lose less water than mature leaves on which tests were made simultaneously. *Typha* showed a greater loss for the young leaves. The average standard loss for the group, including *Typha*, was 1.5735 grams for the young leaves and 1.8966 grams for the mature ones. In the instance of *Typha* the amount lost for the young leaves was 1.5825 grams per 100 square centimeters more than the total amount lost by the other seven species. Leaving *Typha* out of consideration, the mature leaves on the first seven species lost on an average of 3.916 times that of the young leaves.

15. A series of readings taken at different times during the spring, summer and autumn, on *Rosa*, *Catalpa*, and *Acer*, showed a decrease in the standard loss as the leaves grew older. At present the writer is unable to correlate these results with those obtained by simultaneous readings on young and mature leaves.

16. Young leaves of *Convolvulus*, *Psedera* and *Vitis*, showed a more rapid loss of water along the midrib and large veins than on other parts of the leaves. More mature leaves did not show this.

17. Series of readings running through 24 hours in the instances of *Catalpa* and *Sambucus*, and from 3 to 7 readings on *Polygonum amphibium*, *Salix nigra*, *Hibiscus*, *Dianthera*, *Typha angustifolia*, *Amaranthus* and *Zea*, showed that the maximum rate of water loss may occur at different times of day in different species. The series on *Polygonum*, *Salix*, *Hibiscus*, *Dianthera* and *Typha*, show that these water forms have a very decided rhythm in their water loss as do other forms tested, and that their rates of standard water loss varies within a wide range during the day.

18. More data, from many representatives of various groups and associations of plants, are needed before accurate generalizations can be made.

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NEW BOOKS.

A COMPREHENSIVE MEMORANDUM ON

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The salient phases of the subject and its international aspects are examined from this mass of information, and the statistical tables and summaries, as a consequence, are the most comprehensive, authentic and up-to-date available.

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